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STATUS OF THE BESSY VSR PROJECT

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Abstract

BESSY VSR is set out to provide a variable pulse pattern to the BESSY II users. This project is now fully funded and heading into its implementation phase. The pulse pattern, consisting of long and short pulses, require inserting cavities providing a 3^{rd} and a 3.5^{th} harmonic of the fundamental harmonic of the ring. Therefore 1.5 and 1.75 GHz cavities are developed with appropriate higher order mode damping spectrum. Similarly the BESSY II ring and injector chain has to be upgraded to provide appropriate diagnostics and increase the injection efficiency. In this paper we give the current status of the project and give an overview of scientific challenges currently being tackled.

INTRODUCTION

BESSY VSR is the upgrade project of BESSY II to be realized at HZB Berlin [1]. It is fully funded since July 2017 and now heading into its realisation phase. BESSY VSR has been proposed by Gode Wüstefeld *et al.* [2–4]. Its core part are cavities operated at 1.5 GHz and 1.75 GHz. These generate two electrical waves, which yield two types of buckets: short ones when the waves add and long ones when the waves cancel (see Fig. 1). This scheme allows distributing the current in the storage ring into long and short bunches thus providing a high average current and flux with short and long bunches to the users at the same time (Fig. 2(b)).

The installation and operation of these cavities requires quite a few auxiliary systems to operate them:

- a cryoplant providing cooling power of 186 W at 1.8 K and 270 W at 4.2 K with its associated compressors and cooling water system
- solid state amplifiers for generating RF power of 15 kW at Frequencies of 1.5 and 1.75 GHz.

Naturally the cavities and couplers are installed in a cryostat. Furthermore a vacuum system upgrade is foreseen, which is expected to minimize the effect of dust on the cavity system.

Aside to providing the high electrical field, many other activities are required for later successful operation of the machine, which ensure that the bunches can be filled, appropriated diagnosis can be made or the different options are selectable by the user. Details of the different systems are given below.

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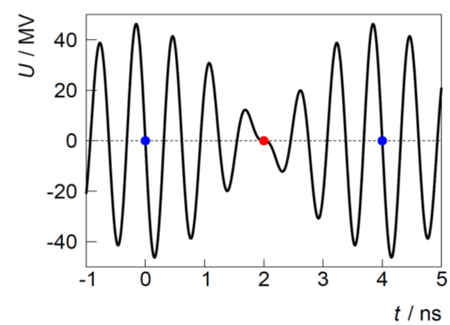

Figure 1: Gradient adding of the BESSY VSR Cavities: red dot…long bunch, blue dot…short bunch; intermediate fixed points will not be populated.

SRF SYSTEM

The core of the whole project are the superconducting radio frequency (SRF) cavities assembled into a string [5]. These are targeted to provide a gradient of 20 MV/m at an operation current of 300 mA; a challenge in itself (see also Fig 3). Furthermore the cavities have to be shadowed off from the synchrotron radiation by bellows, which add impedances to the machine [6]. The smallest bellow will be installed as test setup in the BESSY II machine. The standard pulse pattern (see Fig. 2(b)) as well as single bunch patterns introduce higher order modes (HOM's), which are directed to absorbers (see Fig. 3) recooled by water at room temperature [7]. Similarly the wave energy propagating into the vacuum chamber must be stopped by dielectric absorbers [8].

The fundamental mode couplers are all foreseen to be connected at one side to the cold string (see Fig. 3). These distort the electrical field, which generates transverse kicks [9]. Their impact on the beam is expected to be within limits [10].

BEAM DYNAMICS

Currently two filling patterns are foreseen for BESSY VSR operation: the one shown in Fig 2(b), and a similar one, which basically omits the train of short bunches. The wake fields in the cavities thus vary over time and affect the bunches [11]. This results in a variation of the bunch length (Fig. 2(a)). The beam loss in the BESSY II machine is dominated by Touschek life time, with an average lifetime $\bar{\tau}_t$ of ≈ 3 h. The gas lifetime $\bar{\tau}_g$ is in the order of ≈ 30 h.

Using the foreseen bunch current and length the lifetime and losses are derived applying a scaling approach, see Fig. 2(a) [11]. The forecasted numbers (see Table 1) indicate that beam losses are not yet within limits prescribed

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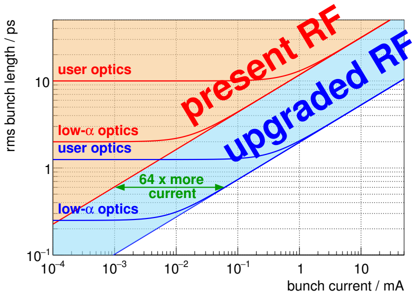
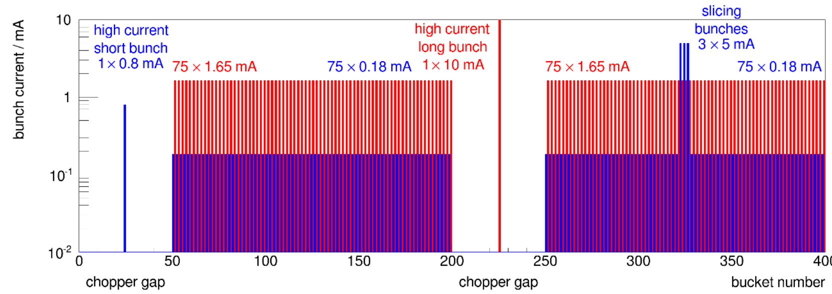


(a) bunch length



(b) fill pattern

Figure 2: BESSY VSR bunch length and fill pattern.

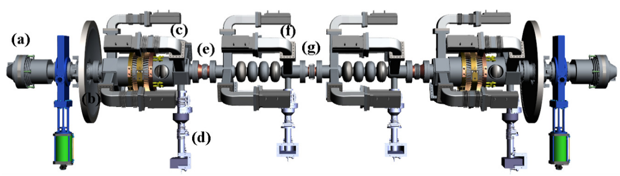


Figure 3: The cold string: a...dielectric absorbers, c,f...HOM absorbers, d...fundamental mode coupler, e,g...shielding bellows.

by authorities. Countermeasures, e.g. reducing the average current, will have to be prepared and discussed as soon these forecasts have been verified by measurements.

Table 1: Bunch resolved Touschek Lifetime for two possible filling scenarios for BESSY VSR. **b**...base scenario, **e**...extended scenario. $\bar{\tau}_t$...average lifetime, $-\mathrm{d}I/\mathrm{d}t$...total loss rate, $\frac{\mathrm{d}I/\mathrm{d}t}{\sum \mathrm{d}I/\mathrm{d}t}$...loss rate normalized by total loss rate.

	$\bar{\tau}_t$ / h		$-\mathrm{d}I/\mathrm{d}t$ / µA s^{-1}		$\frac{\mathrm{d}I/\mathrm{d}t}{\sum \mathrm{d}I/\mathrm{d}t}$ / ‰	
scenario	**b**	**e**	**b**	**e**	**b**	**e**
single bunch						
short	1.3	1.3	0.2	0.2	5.2	5.3
long	1.1	0.9	2.5	2.9	74	90
slicing	0.33	0.34	13	13	370	380
train						
short	–	3.5	–	1.6	–	50
long	3.2	3.7	19	15	550	470
all	2.5	2.5	34	33		

VACUUM SYSTEM

Operating SRF cavities in a "dirty machine"

A workshop was organized by Emmy Sharples, Hartmut Ehmler *et al.* [12] which was dedicated to collect the experience of different labs around the world. The overall impression was that the XFEL project has set the target to aim for, in particular for cavities that have to be operated at a gradient of ≈ 20 MV/m. On the other hand other labs have shown that at modest gradient levels ≈ 6 MV/m requirements are not that constrained. Furthermore Charlie Reece of Jefferson lab showed that even with some accumulation of sizable particulates SRF cavities can be operated; but the operation gradient has to be reduced.

VACUUM SYSTEM UPGRADE

Given the sensitivity of SRF systems to particulates, the vacuum group has investigated two upgrade paths for preparation. Based on the information gathered in the workshop above, the larger package was chosen [13], which is optimized so that the vacuum chambers are made as large as possible and these are fabricated in a manner that the vacuum chambers associated with the different instruments can be assembled in a clean room (Fig. 4).

This leads to

- a vacuum chamber, which is a single piece from the cryostat over the next bending dipole, which will be NEG coated for better pumping speed
- modified beam position monitors, which are part of the vacuum chamber, as the current ones require attaching auxiliaries to it after they have been installed on the chamber
- modified ion pumps on the chamber, which can be left attached to the vacuum chamber during installing the chamber into the magnet lattice
- stages which allow moving the dipole magnets to the side; again an operation flexibility allowing inserting a single vacuum chamber piece into a large section of the magnet lattice

In total the vacuum chambers will be upgraded over a length of 30 m. This upgrade plan is depicted in Fig. 4.

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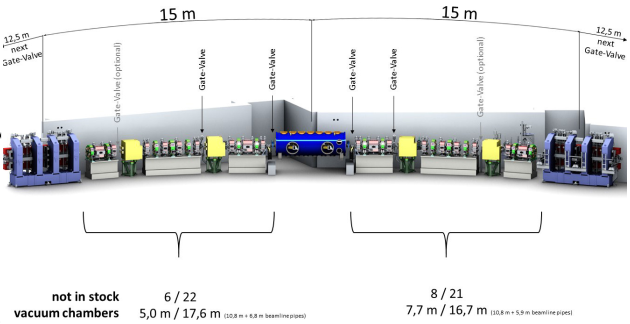

Figure 4: Sketch of the vacuum system upgrade of BESSY VSR

EXISTING INFRASTRUCTURE UPGRADE

Along to all the activities focused on installing and operating the required cavities, a beam separation scheme is under investigation in BESSY II [14]; a possible candiate to separate long and short bunches transversely. Furthermore beam diagnostics is upgraded for the new short bunches [15, 16].

The overall loss within the machine has to be within stringent limits. Thus the life time of the different bunches is a critical parameter; in particular it is expected that the short single bunch has to be refilled frequently.

Upgrade of the Injector Chain

The ultra short bunches and their associated bunches in the machine require to foresee that the injector is enabled to deliver so short bunches that these will match the RF bucket size of the BESSY VSR machine, which will be achieved by installing additional RF gradient with two 500 MHz PETRA style cavities and associated RF power amplifiers [17].

The radiation protection license requires to tightly control the number of electrons that can be tolerated to be lost during operation; furthermore appropriate measures have to be taken that ensure that electrons are filled in the short buckets of the storage ring with sufficient efficiency.

RELIABILITY

BESSY VSR as an upgrade to the BESSY II machine is expected to match or at least come close to the reliability of the BESSY II machine; thus all installed systems will follow the redundant system design as established at the BESSY II machine.

While this is appropriate for most of the systems, a warm up of the cavities has to be analysed more carefully. Even if the upgrade of the vacuum system will ensure that sufficient pumping surfaces and thus pumping speed will be available to the SRF cavity system, the Nb surface of the cavities, operated at 1.8 K will adsorb residual gas. Any operation slip, which results in a short warm up of the cavities above roughly 25 K could induce a significant pressure bump in the beam vacuum system. The value of this pressure bump is considered to depend on the duration, during which the cavities were kept at cryogenic temperature.

On the other hand experience on operating the cryoplants inhouse shows that a trip of the cryoplant for more than half an hour will not allow a restart of the cryoplant for roughly 2 days. While an unavailability of BESSY VSR for a few days is considered acceptable for users at least during first operations, a failure of BESSY II for a few days shall be avoided by all means.

Currently investigations are running on quantifying

1. the pressure bump to be expected,
2. the time required for accumulating significant amounts of residual gas on the cavities
3. and the time required to get back to operation even if the cavities will be heat up to room temperature.

The findings and measurements undertaken will be reported elsewhere.

PROJECT AND RISK CONTROL

All the preparation activities listed above follow the lines outlined in the technical design study [1]; these are now accompanied with standard measures of project control: a cost book summarizing the budget for the required procurements, schedules for the different work packages allowing for tracking progress.

Furthermore risks are collected and reviewed on a regular basis. E.g. to reduce overall project risks the aformentioned test setup will allow measuring the impedance of the bellows, which are required to shadow off the BESSY VSR cavities. Given that this test will be installed soon, their influence can be understood before these bellows have to be installed together with the superconducting cavities.

CONCLUSION

The project BESSY VSR has been fully funded and is currently spinning up with first procurements starting. It is set out to provide a variable pulse pattern to the BESSY II users.

The cavity system has been designed and will be procured soon; furthermore procurements are running for the cryoplant with the tender for the amplifiers to be opened soon. Along with these procurements a detailed project plan is implemented that is considered viable for guiding and following the implementation of BESSY VSR.

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